Active Based-Metasurfaces for Mid-Infrared Optoelectronics Devices

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Abstract : We develop low-temperature (450°C) deposition conditions for vanadium di-oxide phase change material. It permits implementation of tunable mid-infrared meta-surfaces on quantum cascade lasers based heterostructures.

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Summary :

Vanadium di-oxide (VO_2) is a close to room temperature (RT) phase transition material. Its electrical conductivity and optical index change by several orders of magnitude around 68°C [1]. These properties are very promising for applications as imaging, sensing memory devices and optoelectronics. However, the typically high deposition temperature of VO_2 and a large lattice mismatch with respect to typical III-V semiconductor materials hampers its integration with III-V-based optoelectronic devices operating in the infrared (IR) and mid-IR spectral ranges.

In our work, we demonstrate passive and active VO_2-based mid-IR optoelectronic devices. We have developed low temperature pulsed laser deposition of VO_2 on III-V heterostructures and characterized topologically, electrically and optically the VO_2 deposited layers. We observe low roughness, an electrical conductivity change of several orders of magnitude and a high optical reflectivity contrast across the temperature-driven phase transition.

We have then implemented mid-IR metallic meta-surfaces on the VO_2 deposited layers. These frequency-selective meta-surfaces consist of a periodic array of nano-resonators defined by electron beam lithography and lift-off of a 3nm/80nm Titanium/Gold layers. Figure 1 shows scanning electron microscopy (SEM) images of a typical sub wavelength split-ring-resonator (SRR) array.

The frequency response of the SRR can be assumed to be an 'LC' resonator where the metallic loop acts as an inductance (L) and the gap as a capacitor (C) [2]. Figure 2 shows the measured reflectivity as a function of the sample temperature. It exhibits a change of the reflectivity maximum as function of the temperature. It also reveals a maximum frequency shift of hundreds of cm^{-1} of the metamaterial resonance between 65°C and 72°C.

Finally, we have implemented a mid-IR quantum cascade laser (QCL) with a VO_2 layer on its top. The laser operates at λ=7.7 µm and the laser current threshold is only 10% higher than a reference device without VO_2 layer. This demonstration is very promising for the integration of VO_2 on III-V based optoelectronic devices, in order to obtain novel functionalities such as amplitude or phase modulation or wavelength tunability.

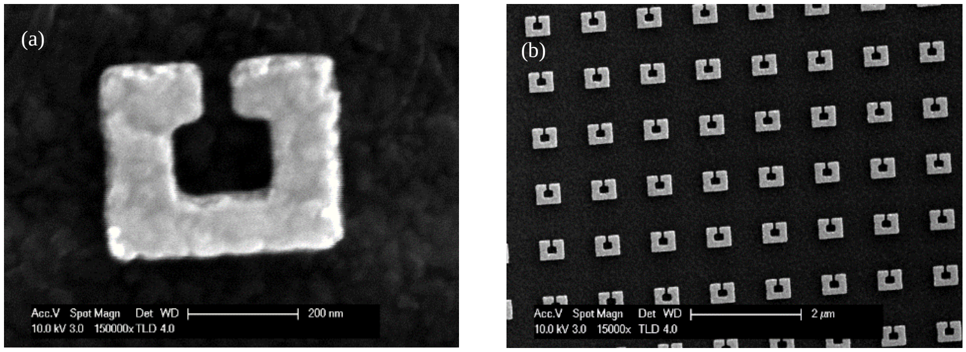

Figure 1 : (a) Scanning electron microscopy (SEM) image of a typical SRR
(b) SEM image of a typical SRR array on a VO_2 layer

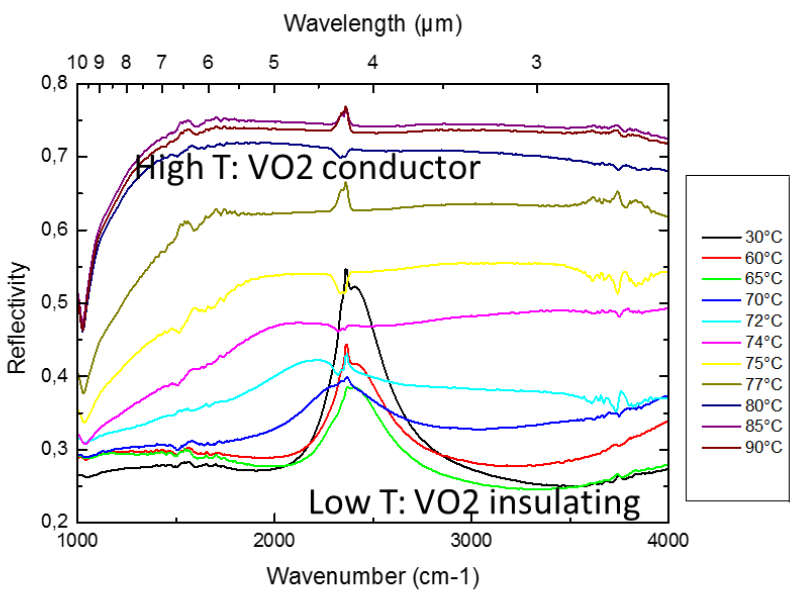

Figure 2: Experimental reflectivity spectra of a VO_2-based meta-surface on a GaAs susbtrate.
The meta-surface is composed of a sub-wavelength array of metallic SRRs implemented on top of the VO_2/GaAs.
Temperature tuning modulates the optical response via the VO_2 phase transition.

References

[1] H.S. Choi, “Mid-infrared properties of a VO2 film near the metal-insulator transition”, Physical Review B, Vol. 54, N°7, 4621-4628 (1996)

[2] S. Tretyakov, “On geometrical scaling of split-ring and double-bar resonators at optical frequencies”, Metamaterials 1, 40-43 (2007)